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THE INFLUENCE OF THE EXCITATION SIGNAL ON MAGNETORHEOLOGICAL DAMPER DYNAMIC BEHAVIOUR

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Abstract: *In the context of improving the comfort and dynamics of the vehicle, the suspension system has been continuously developed and improved, especially using magnetorheological (MR) shock absorbers. The magnetorheological shock absorber can combine the comfort with the dynamic driving, because it allows the damping characteristic to be adapted to the road profile. The main objective of the paper is to analyse the influence of the excitation signal on the dynamic behaviour of the magnetorheological shock absorber in the semi-active suspension. The influence of the electric current intensity on the damping coefficient and the dissipated power will also be studied. The coefficient being the control variable for the semi-active suspension. In this sense, the author carried out a set of experimental measurements with a damping test bench, specially built and equipped with modern equipment. The results obtained from the experimental determinations show a significantly improved comfort when using a magnetorheological shock absorber, compared to a classic one, by the fact that the magnetorheological shock absorber allows to modify the damping coefficient according to the road conditions, thus maintaining the permanent contact between the tire and the road due to increased damping force.*

Key-Words: *Damper. Intensity. Magnetorheological. Excitation. Experimental. Vehicle*

NOMENCLATURE

MR : magnetorheological
k_g : the gas chamber stiffness, N·s/m
c_e : the equivalent viscous damping ratio, N·s/m
$F_{MR}(H)$: the controllable damping force, N
F_f : the friction force, N
$\dot{x}_p$: the piston velocity, m/s
F_d : desired damping, N
C : control gain, N·s/m
F : damping force, N
c_{sky} : skyhook viscous damping ratio, N·s/m

1. INTRODUCTION

When the velocity of a vehicle increases, whether we are talking about cars or trains, the vibrations generated by the interaction of the wheel with the road increase significantly and are deeply felt by their body, leading to major problems related to the ride comfort, quality of the travel, stability and the maintenance of the roads. The vehicle suspension has a very important role in controlling its dynamics, being a basic system both for ride comfort while driving and for maintaining/handling the road.
The road oscillations are a risk factor for passengers of the vehicles, but also a discomfort at the same time [1][2][3].
The magnetorheological damper is based on rheological fluids, which can change their viscosity when a magnetic field operates on them. A MR fluid consists of a mixture of oil (usually a silicone oil) and micro-particles sensitive to the magnetic field (for example iron particles).

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The MR fluid behaves like a normal liquid when magnetic field is not applied. When a magnetic field is applied to the MR fluid, the particles form chains and the fluid becomes very viscous.
The induced force depends directly on the amount of magnetic flux density developed in the effective fluid flow gap of the MR shock absorber. Its adaptive behaviour has led to a rapid growth in such varied engineering applications as basic insolation of civil structures, vehicle suspensions, and several bio-engineering mechanisms through its implementation in various basic MR fluid devices, especially in MR shock absorbers [4][5].
Through different types of signals applied to the suspension, which represents the excitation of the road, the dynamic behaviour of the suspension can be highlighted [6]. Many suspension systems/methods can be used to isolate the vibrations transmitted, such as vehicle suspension systems, cabin suspension systems and seating suspension systems [7].
The design and analysis of the magnetic circuit is an important stage in the design of the magnetorheological shock absorber. The damping force depends on the intensity of the magnetic field, which is affected by the construction of the magnetic circuit and the associated parameters, as well as the diameter of the piston. Unlike passive suspension, variable magnetorheological shock absorber of semi-active suspension can be effectively controlled in terms of shock absorber stiffness based on required values in a given situation [8][9]. As stiffness and damping emulations in semi-active actuators are coupled quantities the control is formulated to prioritize the frequency control by the controlled stiffness [10].
In an MR damper the piston contains coils capable of providing a magnetic field in the holes. Under these conditions, the piston can be considered as a magnetorheological valve, and the damping is the result of the friction between the magnetorheological fluid and the orifices Figure 1.
The area between the neighbouring poles is a route of natural flow. In the middle region of the pole there is a strangulation of the flow and the saturation in this area must be avoided, because it is a critical area for the performance of the shock absorber [11].

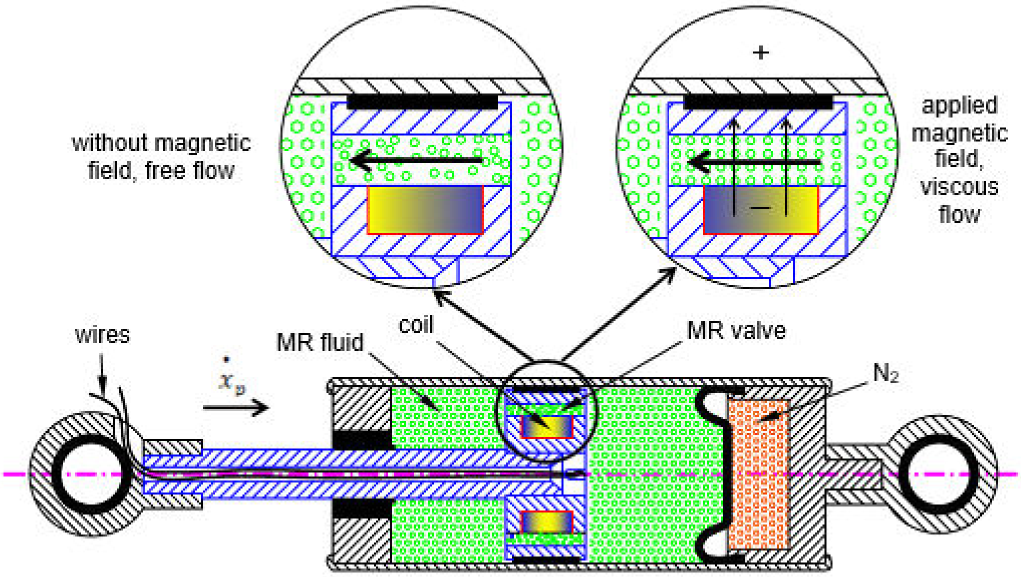

Figure 1. Schematic diagram of a MR shock absorber

When the coil (located inside the piston) is excited with a square pulse voltage emitted by the electronic control unit, a magnetic field is generated which produces the alignment of the magnetic particles. When the coil is not supplied with electricity, the magnetorheological fluid doesn't magnetize, and the iron particles are randomly dispersed inside the fluid, and the fluid behaves like a conventional hydraulic oil. When the coil is supplied, the magnetic field causes the particles to align in the direction of the magnetic flux. The bond strength between the particles is proportional to the strength of the magnetic field. They are positioned transversely to the direction of oil flow, thus limiting the flow of fluid through the piston grooves. The magnetorheological damper can change the damping characteristic much faster compared to a conventional adaptive damper. Depending on the type of damping force variation mechanism, the dampers can be passive, manually adjustable, adaptive [12].

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Using only mechanical valves, passive shock absorbers do not require auxiliary power or control. The manually adjustable ones contain electromechanical actuators, which allow a selection of the predetermined characteristics of the shock absorber valves. Adaptive systems are autonomous and have the capacity to generate force according to road conditions. The available systems are found in several variants, from those with two positions to continuously variable systems. Modification of the stiffness of the suspension, associated with the modification of the damping (so that the relative damping remains unchanged) leads to low variations in the comfort of the vehicle and the safety of ensuring the permanent contact of the wheels with the road. When moving the vehicle, the dynamic forces taken over by the shock absorbers are quite high.
There are numerous studies in the literature based on adaptive control methods, which have the role of producing an improvement in the properties of vehicle suspensions [13][14][15][16][17][19].
Electronically controlled active suspensions can substantially improve driving comfort as well as the road holding characteristics, capability of the vehicle. When the load of the vehicle changes, the suspended mass varies within quite large limits. As the load decreases, there is an increase in relative damping, which is essential for the amplitude of the low frequency oscillations. When the suspended mass decreases, the natural frequency increases, favouring the appearance of the resonance phenomenon at the usual travel speeds. If the damping factor is maintained when the load decreases, the comfort at resonance decreases.

2. MATERIALS AND METHODS

2.1 Control strategy

The semi-active control system performance can be generally improved in an active way, without using large energy sources. The necessary external energy needed to generate the desired control forces of an intelligent suspension it is an important problem that needs to be taken in account in the makings of the controller. For obtaining the desired damping force in a controllable area, we can use three main semi-active methods of control that are different: skyhook, ground hook and sky–ground hook. One of the most popular control logics for the semi-active control systems is the control algorithm Skyhook, because this algorithm is very simple to formulate and easy to implement in practice.
An example for the skyhook controller appliance, that keeps account of the damping control force for the MR damper it is showed in the Figure 2.

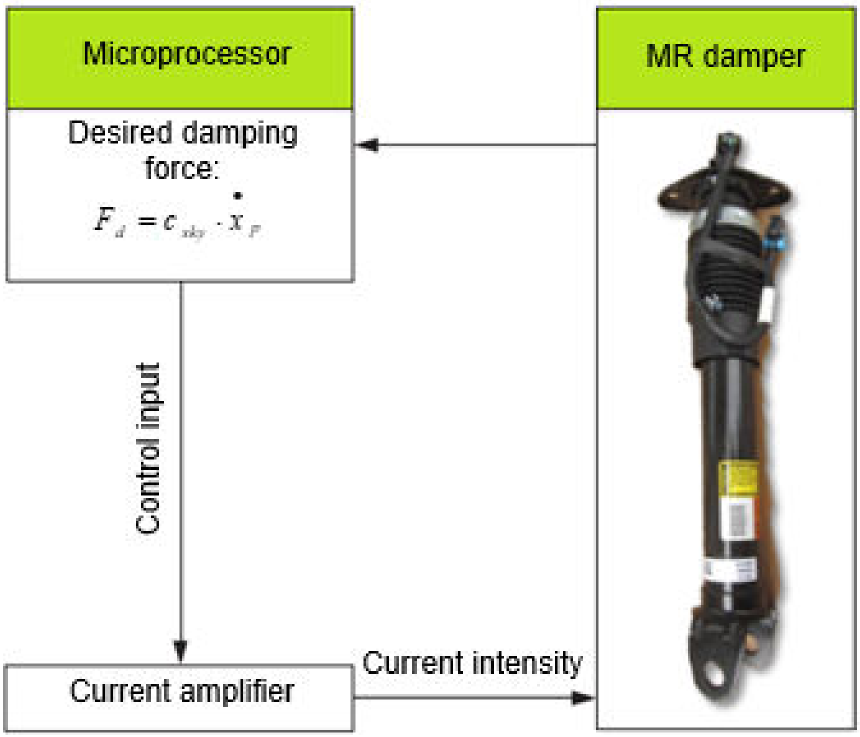

Figure 2. Skyhook damping force control of an MR damper

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The principle of this approach is to design an active suspension control so that the chassis is “linked” to the sky in order to reduce the vertical oscillations of the chassis and the axle independently of each other [18]. The damping force of the damper can be derived from:

$$F = k_g \cdot \dot{x}_p + c_e \cdot \dot{x}_p + F_{MR}(H) + F_f \qquad (1)$$

The controllable damping force depends on the magnetic field *H*. Generally, to implement the MR damper in the suspension system of the car we require a high damping force in the extension movement and a small damping force in the compression movement. If $\dot{x}_p \geq 0$ the piston of the damper is in extension stroke and $F_d = C \cdot \dot{x}_p$ (C = control gain). If $\dot{x}_p < 0$ the piston of the damper is in compression stroke and $F_d = F$ in the absence of the magnetic field [18]. To find a good compromise between comfort and manoeuvrability one way is to shape a skyhook damper. The skyhook damper adapts to the road conditions and minimizes the pitching and rolling tendencies of the automobile.

2.2 Manetorheological dampers test bench

The test bench, designed and made by the author, consists of the main components: electrohydraulic servomechanism, position transducer, force transducer, velocity transducer, accelerometer, hydropneumatics accumulator, MR shock absorber, servo valve, servo cylinder etc. The principle scheme of the installation used for performing the experimental identification is presented in Figure 3 and the details regarding the damper mounting are presented in Figure 4 and Figure 5. For the control of the electrohydraulic servomechanism and for the acquisition of the measured data, a PXI modular platform for industrial test and measurement applications is used, provided with a data acquisition board produced by the National Instruments corporation, assisted by the LabVIEW program produced by the same corporation.

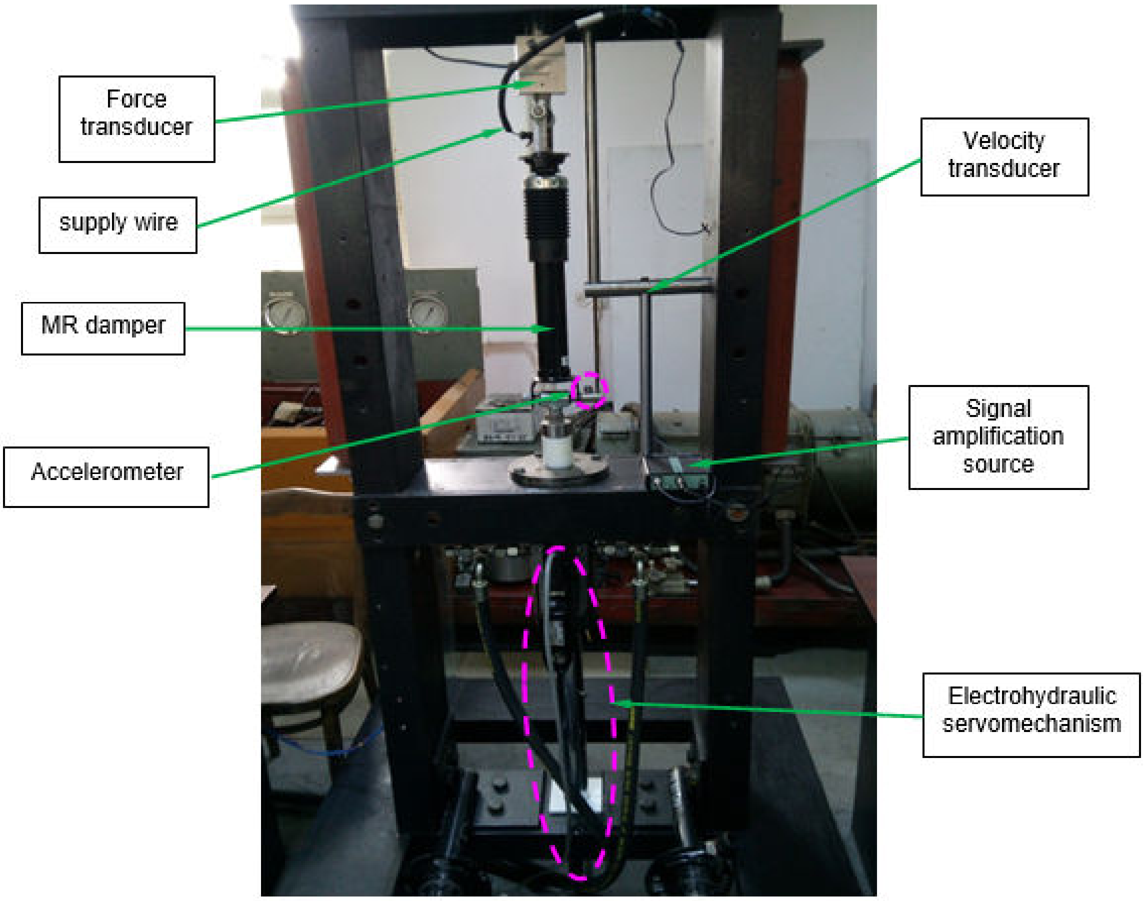

Figure 3. A part of the installation for testing magnetorheological dampers

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Figure 4. Detail regarding the mounting of the shock absorber at the top

Figure 5. Detail regarding the mounting of the shock absorber at the bottom

The excitation of the magnetorheological shock absorber is done with a position signal, like to the real operating situation, a signal which, depending on the type of test performed, can be sinusoidal, triangular or compound.
The output quantity is the damping force developed by the magnetorheological damper, corresponding to the different load velocities. A high speed piezo ceramic force transducer (MTS) is used to measure the damping force developed by the shock absorber. The velocity of the stroke piston is measured by an inductive contactless transducer (SCHEWITZ).
In the case of electromechanical test stands, the frequency is usually changed using either a DC motor or a speed reducer.
Electrohydraulic test systems, much more elastic in terms of control signals, allow easy modification of both sizes of interest. The magnetorheological shock absorber (Delphi) equips the rear axle suspension of the Chevrolet Corvette vehicle.
The electrohydraulic servomechanism is composed from servo cylinder equipped with the proportional distributor and position transducer.
The servomechanism subjected to the experimental research was of electrohydraulic type and had the following characteristics: hydraulic motor type: linear, symmetrical, total piston stroke: 200 mm, piston usable area: 7.65 cm^2, electrohydraulic amplifier type: BOSCH OBE, MOOG series D76 or equivalent, type of electronic controller: linear PID, position transducer type: inductive, non - contact, or resistive, two - track, rated operating pressure: 21 MPa.
To determine the regulation characteristic, the reference signal used was a triangular signal with an amplitude of 9 V and a frequency of 0.02 Hz, which provided the servomechanism with a quasi-stationary operating mode (piston speed was 3.6 mm/s).
The sampling frequency was in this case 10 Hz.
The temperature of the oil in the shock absorber and its body varies sufficiently slowly, being the cumulative result of energy dissipation during the test and of the limited cooling possibilities. Temperature certainly influences performance and tends to reduce the damping force for a given speed. Also, the force due to the gas pressure and its corresponding rigidity increase with increasing temperature. Under these conditions, temperature monitoring is required.
This can be easily done using a thermocouple, together with the appropriate display element.

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3. RESULTS

In this chapter I will present some the experimental results of the tests of magnetorheological shock absorbers, in order to analyse their dynamic behaviour. A triangular and a rectangular signal were chosen as excitation signals. The value of the electric current intensity is 0.5 A, and the excitation frequency is 0.3 Hz Figure 6. The rectangular signal characterizes the operation of the shock absorber in heavy driving conditions, and the triangular one in light driving conditions.

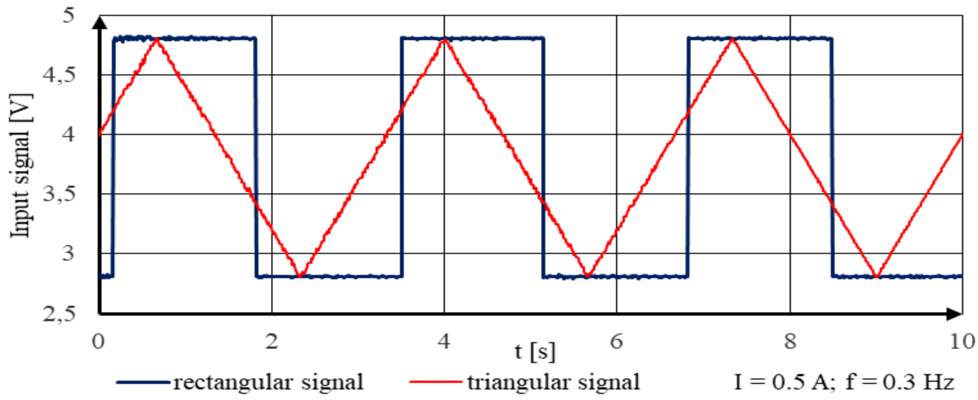

Figure 6. The variation in time of the signal type for a tested magnetorheological damper

The damping characteristics of the damper for the two types of signals are shown in Figure and 7 and Figure 8. We find that the damping force developed by the magnetorheological shock absorber is higher compared to that developed by the classic shock absorber. We also notice that depending on the type of signal, the hysteresis loop also changes. Experimental research has determined the actual damping characteristics and revealed the influence of current intensity on these characteristics.

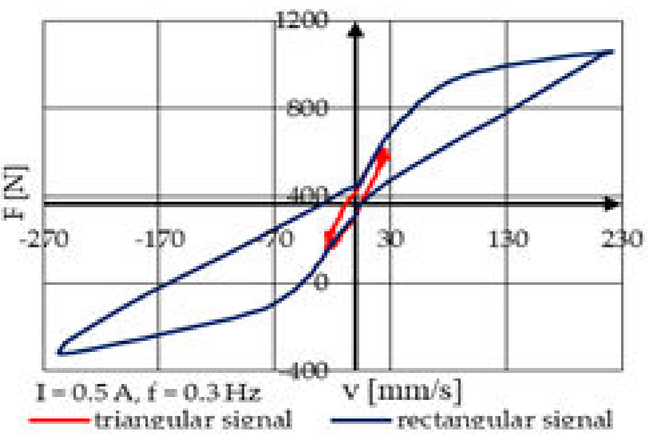

Figure 7. The damping characteristic of the magnetorheological shock absorber in force-velocity coordinates

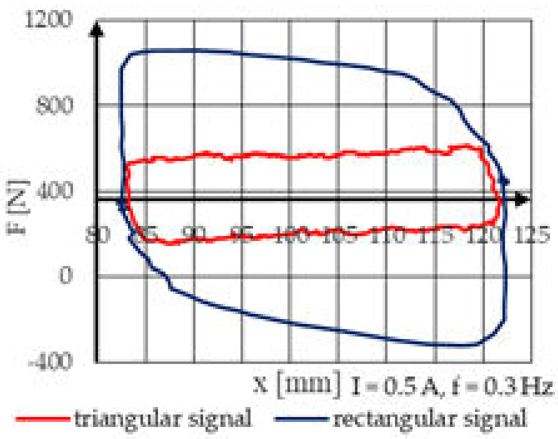

Figure 8. The damping characteristic of the magnetorheological shock absorber in force-displacement coordinates

Figure 9 shows the variation of the maximum and minimum damping coefficient depending on the current intensity, for a magnetorheological damper, for a sinusoidal signal with a frequency of 0.5 Hz. We notice how the magnetorheological shock absorber changes the value of its damping coefficient depending on the value of the electric current intensity. After a higher value of the electric current intensity, over 3 A the trend shows that the value of the damping coefficient of the magnetorheological shock absorber tends to saturate Figure 9. Figure 10 shows the dissipated power corresponding to the maximum forces, for different values of the electric current intensity for a magnetorheological damper, considering a piston speed of approximately 60 mm/s and an input sinusoidal signal at a frequency of 0.5 Hz.

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Over 3 A the tendency is for the dissipation power to saturate as well. The law of variation for the damping coefficient, respectively for the dissipated power by the magnetorheological shock absorber, as a result of the viscous friction approximates a polynomial.
The dissipated power curve, depending on the current intensity, shows a faster variation up to 1 A, then it starts to have a slower variation. The power dissipated by the magnetorheological shock absorber is higher compared to that of the classic shock absorber.

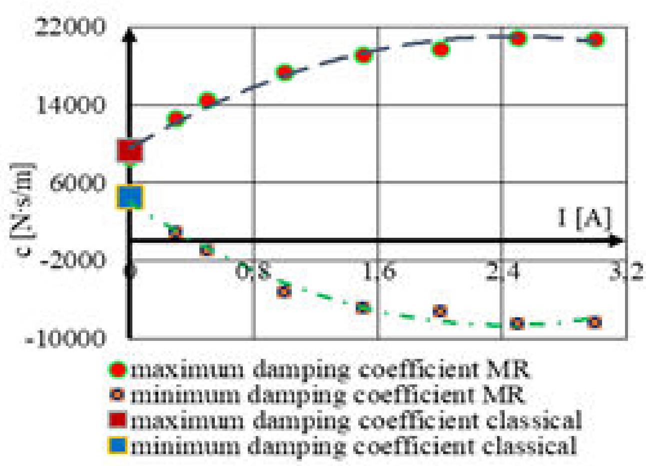

Figure 9. The maximum and minimum damping coefficient depending on the current intensity, for a magneto-rheological damper

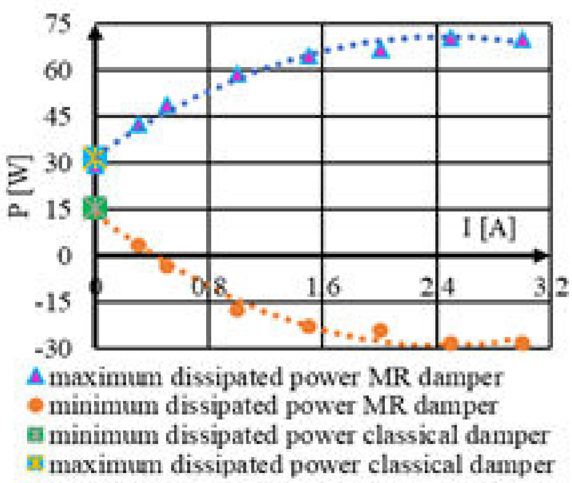

Figure 10. The maximum and minimum dissipate power depending on the current intensity, for a magneto-rheological damper

The experimental research undertaken allowed to determine the real dynamic characteristics of the shock absorber and to identify the influence of the parameters on these characteristics.

4. CONCLUSIONS

Devices that use MR fluids require low power, below 50 W: 12-24 V and 1-2 A [11][18].
Conventional batteries can easily provide this power. This is also confirmed by the results of the experimental research.
Passive suspensions are digitally controlled, thus becoming essential comfort elements of luxury and sports cars. Due to the high cost, active suspensions are mainly used for military vehicles and high-end luxury class vehicles. Semi-active suspensions are beginning to become economically feasible, as they achieve a trade-off between price and performance, offering comfort close to that of an active suspension with an acceptable cost and reasonable fuel consumption.
Among the semi-active suspension variants, the magnetorheological ones are also the most used, because they are cheaper, and the magnetorheological fluid can be controlled more easily, compared to the electrorheological one.
The results obtained from the experimental determinations show a significantly improved comfort when using a magnetorheological shock absorber, compared to a classic one, by the fact that the magnetorheological shock absorber allows to modify the damping coefficient according to the road conditions, thus maintaining the permanent contact between the tire and the road increase in damping force. Following experimental research, it was found that the rectangular input signal demands more damping compared to the rest of the signals. Modification of the stiffness of the suspension, associated with the modification of the damping (so that the relative damping remains unchanged) leads to low variations in the comfort of the car and the safety of ensuring the permanent contact of the wheels with the road. When moving the car, the dynamic forces taken over by the shock absorbers are quite high.
The variation of the damping coefficient depending on the intensity of the electric current shows that it does not vary linearly, but parabolically, the damping coefficient reaching about 21000 N·s/m, at a current of 3 A.
Analysis deduced from the variation of the damping coefficient, the damping force changing its value depending on the value of the damping coefficient, which changes due to the viscosity of the fluid.

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PREDICTION MODEL FOR SEDAN CLASS VEHICLE BRAKING DISTANCE ON A FLAT SURFACE USING EXPERIMENTAL BRAKING TESTS FOR DIFFERENT ROAD SURFACES

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Abstract: *Vehicle braking distance is a critical parameter when it comes to accident reconstruction. Determining the effective vehicle braking distance depends on a couple of parameters such as tire wear, road surface, vehicle type and mass and vehicle braking system. This paper sets on presenting a case for a braking distance model based on real world situations compared to theoretical braking curves. In order to develop this model, experimental tests had to be conducted, on different surfaces such as snow, partial snow and asphalt, using the same type of vehicle and studying its dynamics parameters. Based on the tests taken, a new mathematical model has been obtained using a polynomial function of the second order, for each type of road surface, for a sedan class vehicle, with 25% - 50% worn tires.*

Key-Words: *Vehicle, Braking distance, Safety, Mathematical formulas, Experimental tests*

1. INTRODUCTION

The modern vehicles focus on improving performance and safety, reason why research on the braking system are in a continuous motion of development since the braking system directly affects the safety of the passenger [1][6][7]. The braking distance of a vehicle is most important, especially in the case of accident reconstruction where the travel distance of the vehicle is crucial in solving some cases [10][18]. Braking distance prediction is also important in the field of the new modern active safety systems such as the Autonomous Emergency Braking [2]. These safety systems can quickly detect potential threats on the road such as pedestrians or animals and brake the vehicle in order to avoid a collision [1]. Emergency braking systems are even more critical in the case of heavy vehicles where the stopping distance is greater due to the low declaration rate of these types of vehicles [23][16]. Henderson and Cebon [4] measured the pneumatic systems for heavy vehicles and discovered a reduction of 15% and 22% of the stopping distance using a system developed by Cambridge Vehicle Dynamics Consortium.

Tires are also a key factor for evaluating the braking distance of a vehicle. In Europe, the tire label on each tire, indicates the grade for a few parameters that include the rolling resistance, the wet grip performance and outside road noise [8].

Braking a vehicle requires attention not only to the dynamic part of braking [11][20], but also to various additional physical effects that need a clear understanding of what is their influences on the vehicle behavior when braking in order to achieve a better performance and safety [3][15].

There are systems developed to control the tire slip. Using this system, the braking forces can be adjusted accurately in various and multiple operating conditions and also various road conditions. Maintaining a specified value for tire slip on each wheel, the braking force values can be maximized in order to obtain the shortest stopping distance possible or can be optimized for greater vehicle stability [5][18].

In our study, we focused on the braking and stopping distance of the vehicle by the means of experimental testing and creating an alternative model that will be used to quickly estimate the stopping distance of a specific vehicle. For this study, we will be using only one type of vehicle, a sedan class car and conduct braking tests on different surfaces and velocities using the same parameters for this vehicle.

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2. PRESENT METHODS OF DETERMINING THE BRAKING DISTANCE OBJECTIVES

The present formula used to determine the braking distance relies on couple of parameters such as velocity and road friction coefficient:

$$Sf = \frac{v_0^2 - v_f^2}{26 \cdot \varphi \cdot g} \quad (1)$$

where Sf is the braking distance [m], v0 is the initial velocity [km/h], vf is the final velocity of the vehicle [km/h], f is the friction coefficient between the tire and the road and g is the gravitational acceleration. Tire-road friction coefficient represents the level of adhesion between the contact pattern of the tire and the surface of the road [16]. To get the vehicle stopping distance, the driver's reaction time (0.8- 1 seconds) [9] needs to be added, thus the formula will result in [17, 22]:

$$Sf = v \cdot t + \frac{v_0^2 - v_f^2}{26 \cdot \varphi \cdot g} \quad (2)$$

The further issue with this formula is that the friction coefficient needs to be calculated or chosen from a table of experimental determined values such as the one shown below [20]:

Table 1.
Road surface coefficient values [20]

Road condition	Friction coefficient
Dry quality road	0.7 - 0.8
Dry pavement	0.5 – 0.7
Wet road	0.45 – 0.6
Snow covered road	0.2 – 0.4

The braking tire-road coefficient and the wheel slip are strongly connected, influencing each other as the graph below shows [19].

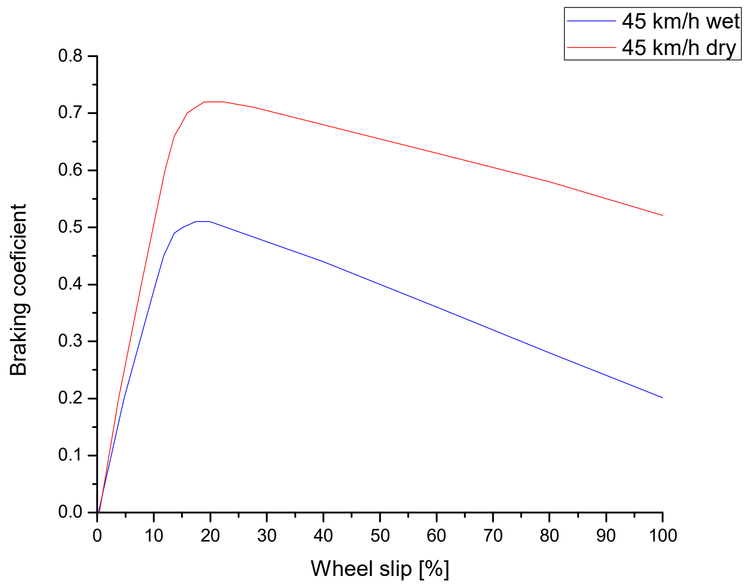

Figure 1. Braking coefficient vs. slip [19]

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The maximum braking coefficient translates into the maximum tire grip force that can be obtained on the road without slipping. The tire-road coefficient can also be calculated using formula 3. It depends on the vehicle deceleration in regards to the gravitational acceleration.

$$\varphi = \left|\frac{a}{g}\right| \tag{3}$$

Where *a*, is the vehicle's deceleration rate. Also, the estimation of the road friction coefficient is a potential useful parameter for modern active safety systems [14]. Paul and Velenis developed an algorithm in order to estimate the critical conditions when the front or rear of the vehicles wheels approached the limit of adhesion in the braking phase and can be incorporated by brake control systems such as the ABS [12]. Another way of determining the friction coefficient in real time is by using an extended Kalman filter and a Bayesian decision making algorithm [13].
The vehicle mean deceleration can be calculated using the formula.

$$a = \frac{\Delta v}{\Delta t} \tag{4}$$

The deceleration of the vehicle can be obtained using various methods. The method chosen to collect velocity data for our research was by using a GPS system, comprised of a laptop, special software and two sensors, model Garmin 18x that can track multiple satellites for fast accurate positioning and velocity estimation at a high acquisition frequencies.
Below is a graph showing the braking distances on various surfaces.

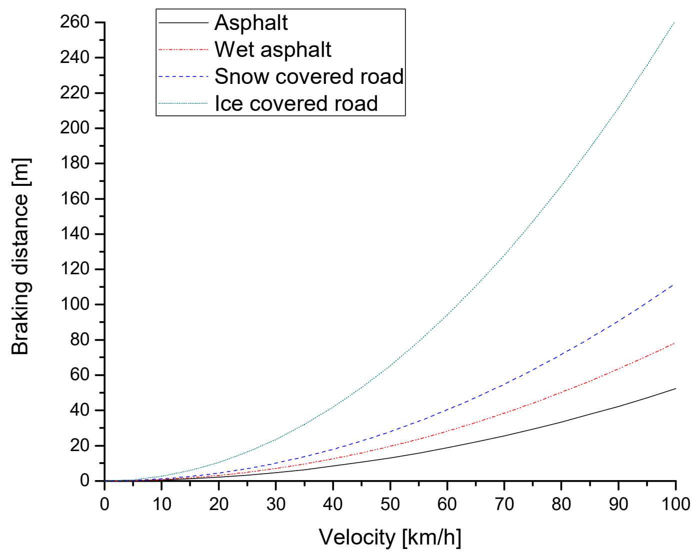

Figure 2. Graph showing the braking distance on different surfaces

In figure 2 there are presented the braking curves determined using formula (1). For the calculus, the friction coefficient was chosen for each surface from table 1. This is a theoretical calculation and an ideal braking distance result. In practice, the friction coefficient on different surfaces may vary from the theoretical model, so the scope of this study was to determine several curve models based on real experimental braking tests in order to have a more accurate representation of the braking distances on various surfaces. A study shows that for a family car (sedan class vehicle) the braking distances vary when the reaction time is added compared to those shown in figure 1 [21]. Here we can see different stopping distances for various velocities including the reaction time of the driver. Depending on the speed, the reaction time differs, from 17 m at 40 km/h up to 46 m at a velocity of 110 km/h.

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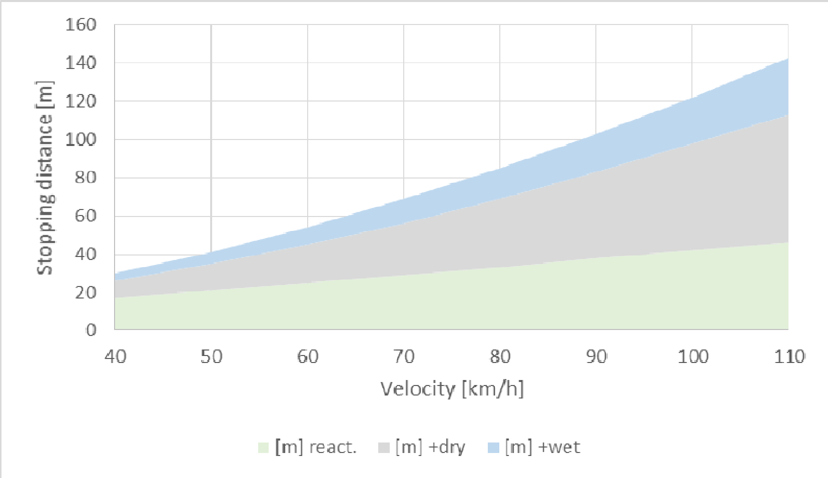

Figure 3. Graph showing the stopping distance for an average family vehicle [21]

3. OBJECTIVES

Objectives for this paper were:

- To conduct experimental braking tests on a flat road and on different surfaces using the same type of vehicle and parameters.
- To use the data obtained from the experimental tests in order to determine an alternative, simpler formula to calculate the braking distance of a specific type of vehicle on different road surfaces.
- To validate the model using theoretical curves.

4. EXPERIMENTAL TESTING METHOD

The basic setup used to perform the experimental tests is presented in figure 4. The vehicle was equipped with two GPS sensors, model Garmin 18x capable or recording with a frequency of 5 Hz, with 20 millisecond increments, from 20 ms up to 980 ms with 1 microsecond accuracy, mounted on the roof of the vehicle relative to the center of mass position that are used to record the variation of the vehicle's velocity. The vehicle was a sedan class equipped with ABS, ESP and ASR systems. The braking system is comprised of ventilated discs with caliper on the front wheels and normal braking discs on the rear. Winter tires were used with the dimensions 195/65 R15 T with a 25% - 50% wear.
A total number of 33 braking tests were conducted – minimum tire degradation, recommended tire pressure values -, of which 11 tests conducted on asphalt, 11 on wet asphalt and 11 on snow surface. Some of the data is presented in the next graph. The velocity values vary in time and are presented from the moment when the vehicle braking was initiated to the moment the vehicle reached full stop (0 km/h).
In figure 5 some curves from selected tests are presented with the scope to clarify the variation of the vehicle's velocity. These tests represent braking at 50 km/h on snow and asphalt surfaces. More braking tests were conducted at different velocities: 30 km/h, 50 km/h and 70 km/h. Some of the test results are presented in figure 6.

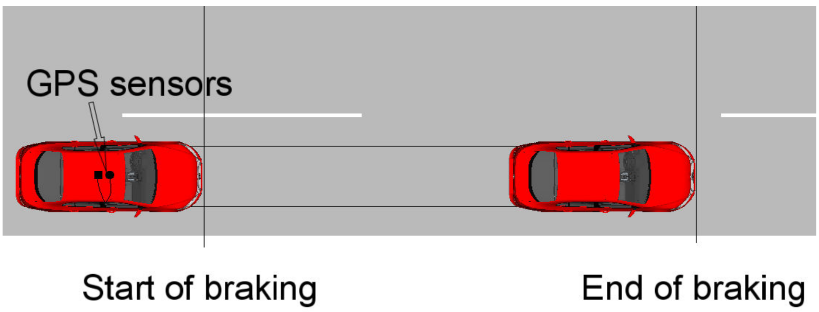

Figure 4. Experimental testing method

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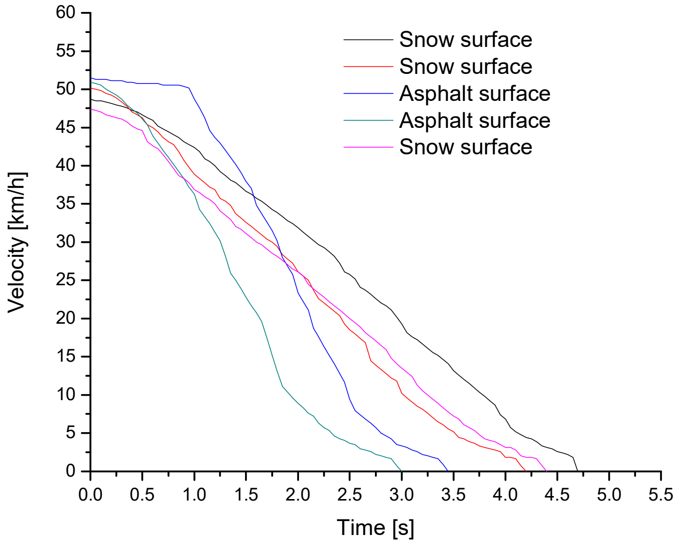

Figure 5. Velocity graph resulted from GPS data

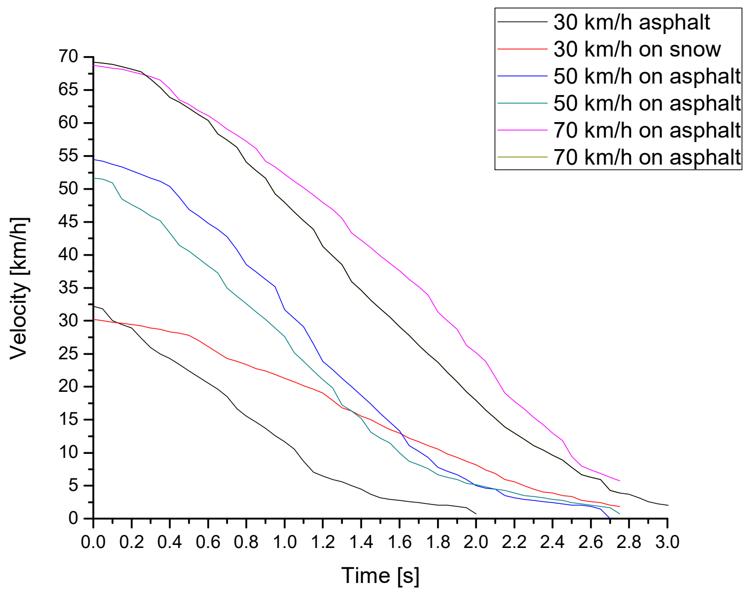

Figure 6. Braking velocities from GPS data

From the recorded data, the traveled distance of the vehicle was calculated using the formula 5. This formula describes the integration of the velocity over time:

$$d(t) = d_0 + \int_0^t v dt \qquad (5)$$

The distance calculated is the actual braking distance of the vehicle.
It is considered from the moment the velocity is starting to decent until it reaches full stop (0 km/h).

5. TEST RESULTS

Using the recorded data from the experimental tests, the braking distance and velocity curve was obtained for every brake velocity tested. Multiple tests results (velocty and braking distance) were plotted for the same surface in order to create a polynomial trendline. Three surfaces were considered relevant within the scope of our experimental case: asphalt, wet asphalt and snow surfaces.

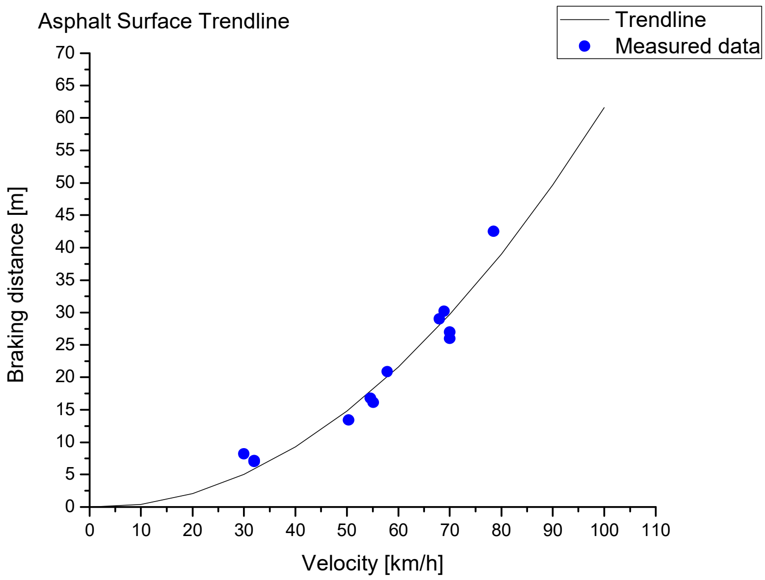

Figure 7. Graph showing the measured braking distance values and the interpolation trend line for asphalt surface

In figure 7, a number of 11 asphalt surface tests are presented for different velocities. By using the polynomial function of the second order a trend line was obtained representing the determined braking distance curve. This polynomial function is considered here as an alternative braking distance solution. In a similar way, trend line for wet asphalt was obtained, which is presented in the figure 8. For this scenario, 5 tests at different velocities were used to obtain a polynomial function of the third order.

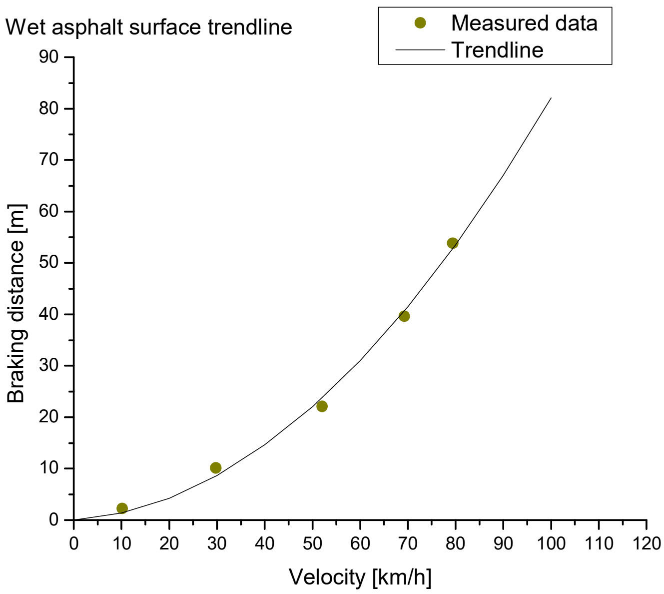

Figure 8. Graph showing the measured braking distance and the interpolation trend line for wet asphalt

For snow surface, the results are shown in figure 9. In this figure the trend line was obtained from 6 tests using a polynomial function of the second order. The previously resulted curves will be validated by comparison with the theoretical calculated braking distance curves.

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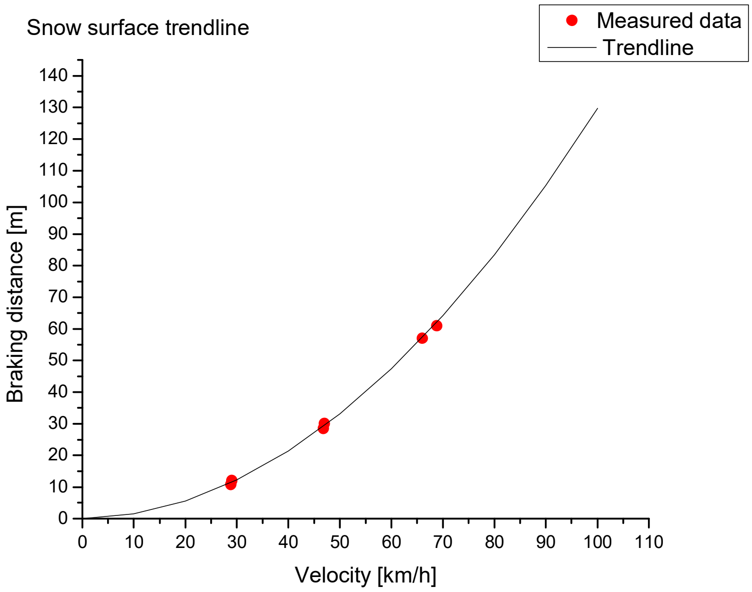

Figure 9. Graph showing the measured braking distance and the interpolation trend line for snow surface

6. PROPOSED BRAKING DISTANCE MODEL EQUATIONS

Using the polynomial functions, equations were determined. These are considered as an alternative way of calculating the braking distance of a vehicle. The vehicle velocity is expressed in km/h.
So, for asphalt surface, the formula determined is:

$$B_{da} = 0.0064 \cdot v^2 - 0.024 \cdot v \quad (6)$$

This formula calculates only the effective braking distance of the vehicle. If the reaction time formula is added, we can calculate the effective stoping distance of the vehicle.

$$S_{da} = (0.0064 \cdot v^2 - 0.024 \cdot v) + [(v \cdot t_r)/3.6] \quad (7)$$

Where *v* is the velocity of the vehicle [km/h] and *tr* is the reaction time [s]. The reaction time of the driver is considered around 1 second, where the human reaction is 0.8 seconds and 0.2 seconds is the braking system lag.
From the tests, on wet asphalt surface, the formula was determined with the polynom of the third order:

$$B_{dwa} = 0.0076 \cdot v^2 + 0.0611 \cdot v \quad (8)$$

Also adding the reaction time will result in the total stopping distance of the vehicle:

$$S_{dwa} = (0.0076 \cdot v^2 + 0.0611 \cdot v) + \frac{v \cdot t_r}{3.6} \quad (9)$$

In a similar way for snow surface, using the trend line polynomial function, the resulted equation is:

$$B_{ds} = 0.0127 \cdot v^2 + 0.0273 \cdot v \quad (10)$$

As before, this formula calculates only the braking distance and in order to obtain the stopping distance, the reaction time needs to be added to the formula.

$$S_{ds} = (0.0127 \cdot v^2 + 0.0273 \cdot v) + [(v \cdot t_r)/3.6] \quad (11)$$

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7. VALIDATION OF THE MODEL WITH ANALYTICAL MODEL

Validation of the model was done by comparison with theoretical calculation curves.
Errors were calculated and the relative error were obtained.
The equation is based on the absolute mean defined by this formula:

$$\Delta m = \left|\overline{m} - m_i\right| \quad (12)$$

Where m - the measured size, $\overline{m}$ - the absolute value of the magnitude, i - the number of measurements. The absolute mean error Δm is calculated with the relation:

$$\Delta\overline{\mathrm{m}} = \frac{\Delta m_1 + \Delta m_2 + ... + \Delta m_i}{i} \quad (13)$$

The relative error is defined as the ratio between absolute error and absolute value of exact size:

$$\frac{\Delta\overline{\mathrm{m}}}{\overline{m}}(\%) = \frac{\Delta m}{\overline{m}} \cdot 100 \quad (14)$$

The theoretical calculations were obtained using formula (1) and with a friction coefficient that matched the ones from the trend line of the experimental tests. For asphalt, the friction coefficient resulted was 0.65. A graph was obtained for the range velocities of 0 to 100 km/h (figure 10). It can be seen that the model and the theoretical calculation match with an average relative error of 2.12% and a minimum relative error of 0.01%. The curves of both the model and the equation have a similar pattern and overlap giving the model a valid use across all tested velocities. The accuracy of our model is 97.88% for velocities up to 100 km/h and 99.4% for velocities between 50 km/h and 100 km/h.
In the figure 11 the similar method was used for wet asphalt.
In this comparison, the friction coefficient obtained was about 0.5 corresponding to a wet asphalt surface. It can be seen that the model and the theoretical formula match with an average relative error of 3.55% with a minimum of 0.13%, giving this model a 96.45% accuracy for velocities up to 100 km/h and an accuracy of 99% for velocities between 50 km/h and 100 km/h.
This error is minimal and it is to be considered valid. The final model validation was for snow surface and it is presented in the figure 12. Also, for this graph, the theoretical calculation revealed a friction coefficient of 0.3, corresponding to a snow surface.

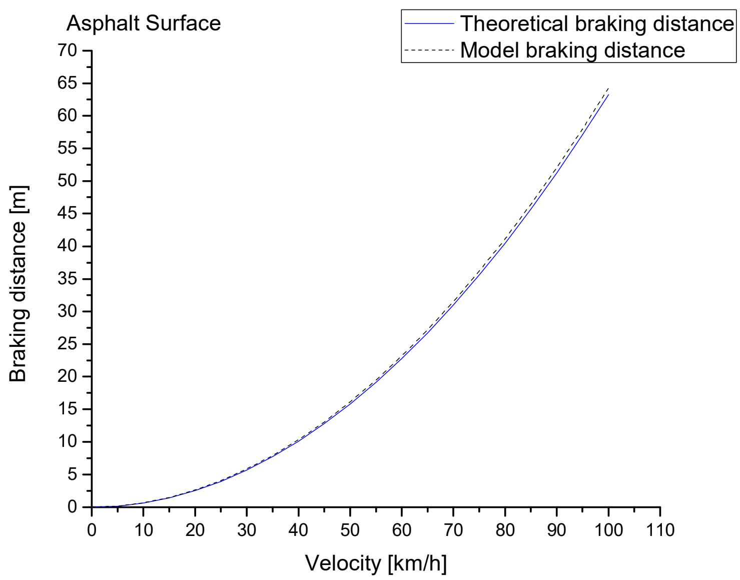

Figure 10. Graph showing the comparison between the theoretical calculated braking distance and the model formula for asphalt

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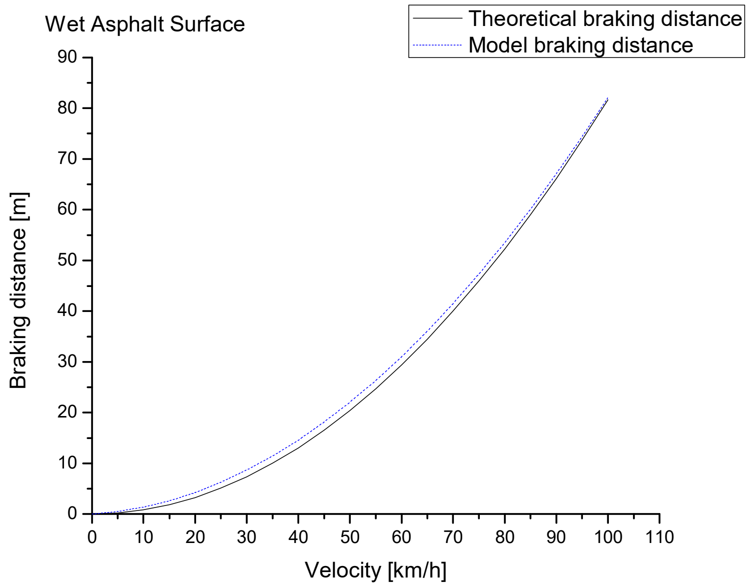

Figure 11. Graph showing the comparison between the theoretical calculated braking distance and the model formula for wet asphalt

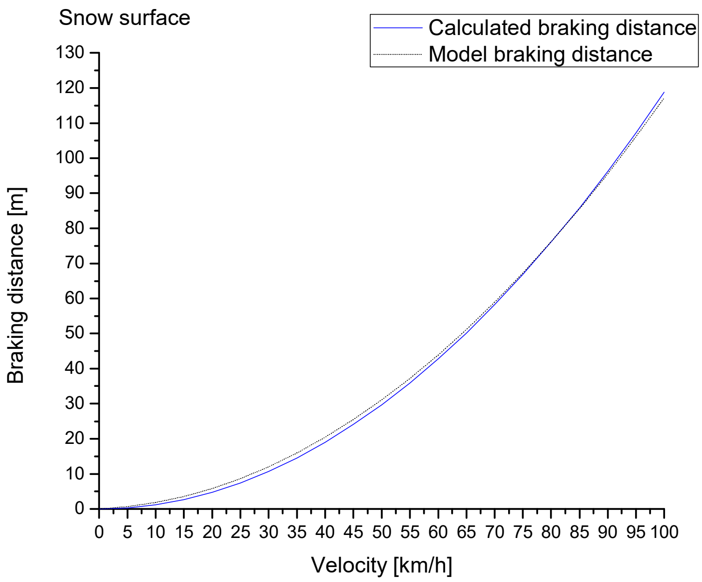

Figure 12. Graph showing the comparison between the theoretical calculated braking distance and the model formula for snow

The model for this case is the most accurate (98.97%) and matches the theoretical model, having a relative error of only 1.03% on average with a minimum of 0.02% for velocities up to 100 km/h and an accuracy of 99.73% between 50 km/h and 100 km/h. The curves match up and make a good representation of the functionality of the model.

6. CONCLUSION

In this study, a fast and highly accurate braking distance prediction model – based on experimental testing - was developed through proposed equations and validated successfully by means of comparison with the theoretical model. The accuracy of the model has been calculated and revealed that for the surfaces tested the model is most accurate at the velocities between 50 km/h and 100 km/h. For asphalt, the accuracy in that range is 99.4%, for wet asphalt it is 99.0% and for snow the accuracy is 99.73%, while for the entire range, starting 10 km/h up, the accuracy values are as follows: 97.88% for dry asphalt, 96.45% for wet asphalt and 98.97 % for snow conditions. It is to be considered that the proposed model presents high accuracy within the limits and scope of our study, regarding the vehicle class, road surface and velocity range tested, with the advantage of quick calculation for the specific friction coefficients used.

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IDENTIFY THE FACTORS INFLUENCING NEW PRODUCT DESIGN AND DEVELOPMENT USING THE MODULAR PRODUCT PLATFORM IN THE AUTOMOTIVE INDUSTRY

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Abstract: *The new product design and development process faces numerous challenges in the automotive industry, and one of the strategies to meet these challenges is the use of modular product platforms. However, the use of this method in Iranian automobile production has not been long and the factors affecting it have not been determined. In this study, based on a qualitative research method, the researchers tried to identify these components. The results show that the four components have the most effect: 1) Technology Development, 2) Product Structure Development, 3) Strategy Development and 4) Organizational Development, which accordingly recommends any type of product design and development in the Iranian automotive industry taking into account all aspects of this set.*

Keywords: *modularity, modular platform, product architecture*

NOMENCLATURE

NPD – New Product Development
R&D – Research and Development

1. INTRODUCTION

Increasing technology changes, market competition and shortening product life have led companies in various industries to innovate and deliver new products at a faster rate, more efficiency and quality (El Maraghy et al., 2013). Therefore, customers are looking for newer, more advanced products that fit their needs (Kotabe and Kothari, 2016). Nowadays companies have little ability to compete without presenting new products. Without a new product design and development, it would be impossible to increase market share and profitability (Mates et al., 2008). The process of designing and developing new product is one of the core capabilities of organizations. The process of designing and developing a new product is a knowledge-driven operation and organizations need sufficient knowledge and information to succeed (Mohammadi et al., 2018). The new product design and development process is a procedure in which an organization utilizes all of its resources, capabilities in the form of multi-purpose teams to create a new and innovative product or to develop an existing product (Morgan and Berthon, 2018). So that product development is seen as a key process for improvement and reorganization. The expanding scope of new product design and development research has expanded to such an extent that it has led to the creation of a broad body of extensive research in the field of production management knowledge (Zhang et al., 2017). According to Sheng et al. (2016) creating a competitive new product requires the right balance between three elements: the ideal product innovation process, effective leadership from top management, and a supportive work environment.
The main purpose of this article is to identify the main factors influencing the design and development of a new product using the platform module in the Iranian automotive space. Therefore, the researchers recognized the necessity of creating a comprehensive explanation and localizing it based on the evaluation of the opinions of authorities and internal experts.

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As such, the present paper systematically reviews and analyzes existing literature on modular platform product design and development factors, based on research achievements published during 1996 to 2019 in internally and externally validated classified and arranged databases. Identifying key components of product development by using modular platform in Iranian automobile industry has identified and delineated the dominant conceptual framework in these researches based on the opinion of domestic and Iranian experts.

2. THEORETICAL BASIS

In this section of the paper, we review the theoretical foundations and background of the research. The relationship among strategy, structure, and product development should be considered in the context of multiple and related concepts such as: architecture, functionality, family and platform product modules. Product function means what the product has the ability to do (Ulrich, 1995). The module is part of the functional unit of a product (Baldwin et al., 1997), (Lundqvist et al., 1996), (Wilhelm, 1997).
A module is defined as a structure independent of a larger system with a specific function (Otto, 2016). Modularity can address standards, including specifications, design planning, manufacturing process, maintenance and service of a product (Wan et al., 2019). Product architecture is the function of a product being assigned to its physical parts (Ulrich et al., 1994). In 1995, Ulrich explored the relationship between product architecture and product strategy and tried to explain it in product development. Also, the concept of platform has received a lot of attention to the relationship between product development and payment operations management (Wheelwright et al., 1992), (Cusumano et al., 1992).
From a production and assembly standpoint, the platform means focusing on the sharing of machines, tools, and assembly lines (Muffatto et al., 1998). The platform is also able to structure the organization (Calabrese, 1997). The product platform also has the capability to adapt to open architecture, in other words, the product platform is capable of responding to mass production with customization (Zhang et al., 2017). Examination of key success Costa and Jongen (2016) studied research using reference groups in the process and conducted their research based on the Cooper model. They also identified eight steps for product development. Looking at the past, especially in recent years, confirms the existence of a rich record of research trends in the concept of new product design and development. According to Peterson (2005) and Sheng et al. (2016), creating a competitive new product requires the right balance between three elements: the ideal product innovation process, effective leadership from senior management, and a supportive work environment.
The model presented in Figure 1, which can be considered as an internal part of the hypothetical engine of innovation, assists in coordinating and balancing the mentioned elements by utilizing strategic management, portfolio management and technical issues.

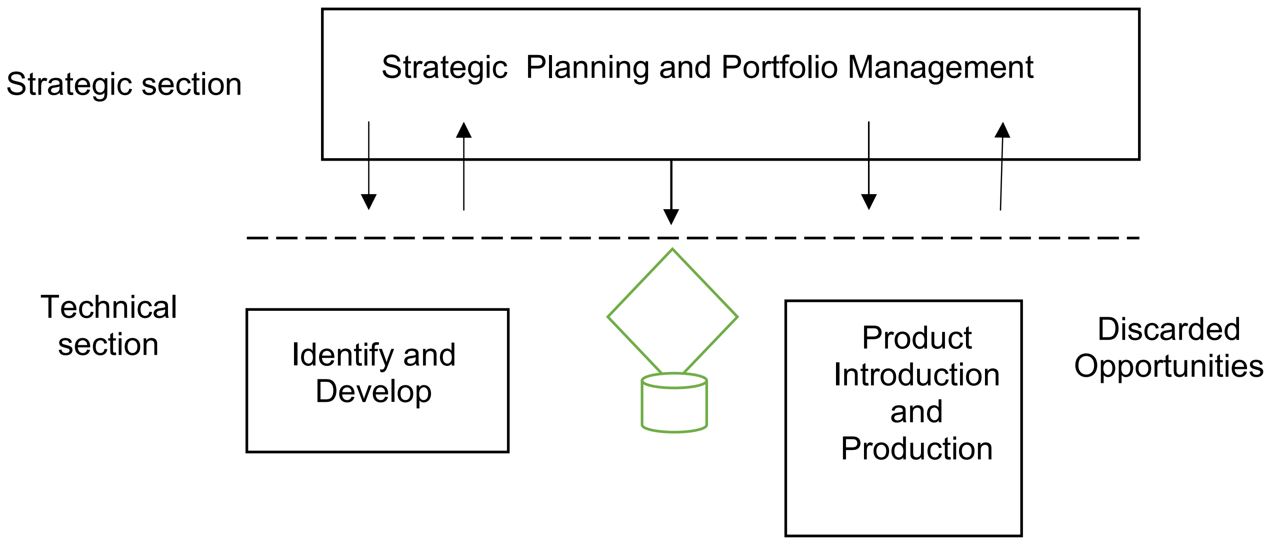

Figure 1. Competitive new product design and development process (Sheng et al., 2016)

Today, most organizations are looking for competitive advantage factors and developing new products helps organizations maintain their competitive position (Radfar et al., 2016).

A study of the factors affecting the success of NPD projects in the manufacturing industries of several advanced countries such as the United States, Canada, Germany, and Belgium by Wang (2018) showed that: 1) the use of multifunctional teams and the focus on dedicated teams; 2) Using research market 3) Market test, initial evaluation of product and production as well as end customer reviews; 4)The quality of the 2 and 3-degree advertising, or the degree to which the company is present in international markets, can be seen as influencing the success of NPD projects. In-house research has also taken into account the factors affecting the success of new product design and development.

3. RESEARCH METHODOLOGY

The present study is implemented in two general stages: First, reviewing the literature and identifying the most important elements (factors, indicators, measures, etc.) in the success of new product design and development using modular product platforms. Second, semi-guided interviews with automotive experts in the phenomenon under study (including managers and car designers) that commented on identified items. A content analysis was used to evaluate the views. In general, content analysis can be done with three categories: approach, evaluation and correlation. The interviewees were selected by purposeful (directional sampling) and snowball method. Given that Kuala considers the sample size between 1 and 2 to be appropriate for such research. While studying the results of the theoretical studies, the researchers were finally able to access the 17 experts in the field of new product design and development in the automotive industry with at least five new products in the past 5 years. The data collection process at this stage was that the interviewers first read the metrics identified in the research literature and then explained, completed, or critiqued them. The interviews continued until the theoretical saturation. The interview time of the experts was this study was at least 80 and 140 minutes maximally.

4. DISCUSSION

After examining the categorical content in the form of the aforementioned process, the initial codes fall into four main categories: (1) technology development, (2) product structure development, (3) strategy development, and (4) organizational development. Table (1) shows the results. These are, in fact, the important components of the success of the new product design and development process in the automotive industry and are illustrated in Figure 2. Considering the structure shown in Table (1) and Figure (2), each of the main categories will be described below.

Table 1.
Main components and their corresponding subcategories

<table>
<tr><td rowspan="5">Successful components of new product design and development using a platform module</td><td>Main components</td><td>Sub-Components</td></tr>
<tr><td>Technology development</td><td>Technical solution
Product architecture</td></tr>
<tr><td>Product structure development</td><td>Product performance
Architecture</td></tr>
<tr><td>Strategy development</td><td>Product idea
Product basket
Specializing in contractors</td></tr>
<tr><td>Organizational development</td><td>Organization with product design and development process capability</td></tr>
</table>

4.1 Technology development

When designing and developing a new product with the use of a platform module everywhere, it is always the first thing that comes to mind when changing production systems and creating a product with „higher capabilities”. But what is important is that technical development is not limited to such decisions. As shown in table (2) of the selective codes for the category of technology development (6 items), these activities have a very broad scope.

4.1.1 Partial or total change in product technology

New product design and development is a gradual issue that has been mentioned in the studies of Liu et al. (2005) and Ozer (2006). In general, what most experts in the technical development field were

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saying is: are you looking for a partial product development? Or is your goal to fully develop and launch a highly reputable product? For example: Automakers have stated that: „For some models only the engine and chassis have been modified and in some cases even the car suspension, transmission and body have undergone changes, so you must purchase new equipment and consider a lot of requirements”.

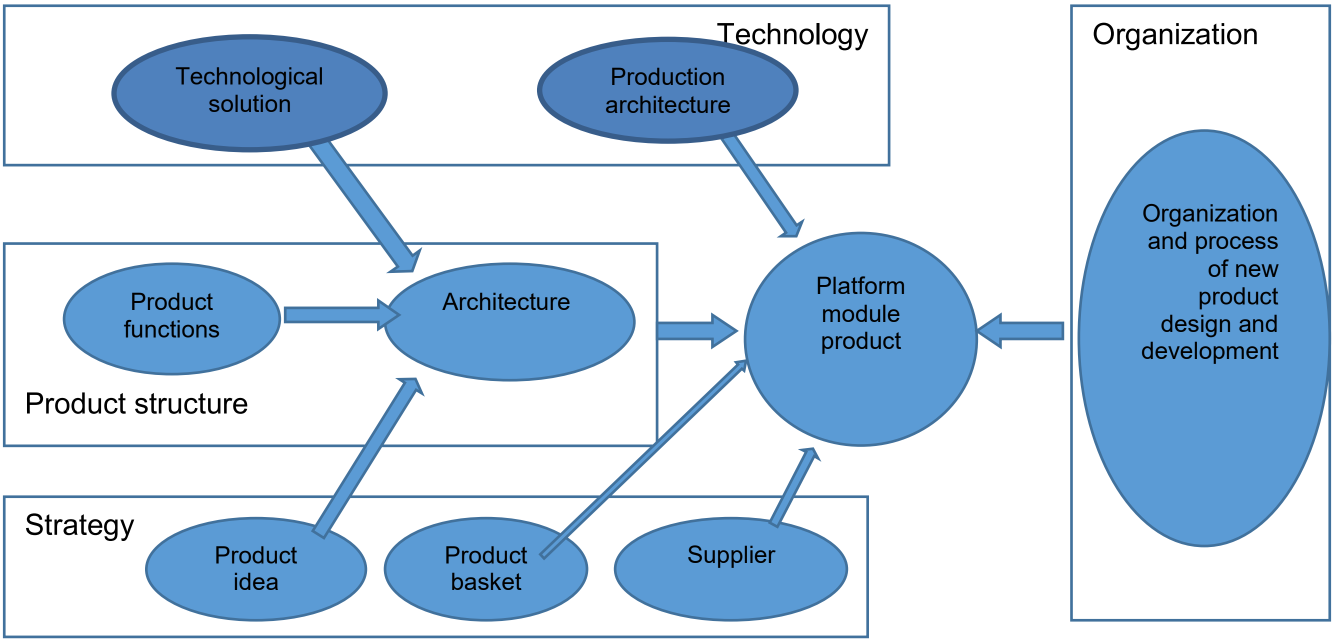

Figure 2. Components of the new product design and development using the platform module

Table 2.
Selected Codes for Technical Development Categories

Main-Components	Sub-Components	Selective codes
Technology Development in Modular Platform	Technical solution Product architecture	Partial or total change in product technology The prototype includes all features Pay attention to the expense incurred in the prototype The design of the product is virtual and varied Product testing in terms of customer feedback on the use of new machines

4.1.2 The prototype includes all features

Prototype placement in new product design and development is a topic discussed in the studies by Petersen et al. (2005). The manager said: „If we are going to spend money and offer a specialized product, it should be a perfect product. We can't market based on an incomplete sample. The risk of such an investment is very high”.

4.1.3 Pay attention to the expense incurred in the prototype

One of the important features is the design and development of a new product using the platform module in cost discussion, and much of it is related to the prototype (Matsui et al., 2007). „We've been able to reduce production costs significantly by using a very simple in-line approach!" says product development experts. „But in order to reduce the price of the product must not affect the customer's trust and attractiveness of the product market. We introduced the product with new design, new name and price”.

4.1.4 The design of the product is virtual and varied

In the new product design and development approach using platform modules, a specialized software can be used to design the production processes prototypes, simulate and correct them (Lai et al., 2012). According to one of the interviewed executives, new product design has a huge impact on its branding and customer attraction. It may be possible to market a same product in several different designs and the customer will evaluate them all in one way.

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4.1.5 Test product in terms of customer feedback on the use of new machines

One of the important steps in launching a product pilot market is to test the latest potential problems and try to deliver an optimal new product (Marion, 2009). In this order, one of the executives with large experience says: „no matter how many new products you market, it's important how much your customers understand the new product differences”. The use of new machines is a valuable competitive advantage in any industry (To et al., 2009).

4.2 Product structure development

The development of product structure further implies that the nature and outlook of the company should be appropriately developed so that the customer's mind is ready for acceptance of the new product (Millson and al., 2006). For this purpose, four selective codes have been proposed which can be seen in Table (3).

Table 3.
Selected codes for product structure development categories

Main-Components	Sub-Components	Selective codes
Development of product structure in modular platform	Product performance	The degree of product difference from market competitors Production of homogeneous or heterogeneous products being different
	Architecture	Full and accurate definition of product features

4.2.1 The degree of product difference from competitors

What is most important in designing and developing a new product using a platform module for the customer is its uniqueness (Ozer, 2006). Customers are always looking for something that is different (not necessarily the best). Create a marketplace that looks more customer-friendly than competitors.

4.2.2 Production of homogeneous or heterogeneous products being different

Another crucial aspect of platform module production is the question of whether to upgrade to the same products and continue to innovate in the same product type? (Buyukozkan and al., 2002) or choose a different product from what we produced in the past? Choosing this decision is very important for the future of the company and the product. Competitive advantage is what makes a customer prefer one brand to another, or a new product to an old product of the same brand (Song and Noh, 2006).
The platform is aligned with the company's goals so that a defined advantage can help enhance the brand's product portfolio.

4.2.3 Full and accurate definition of product features

It is important to create a good competitive advantage to define product characteristics (Schmidt, 2005). This definition should be well-suited to engineers, managers and operational staff. One manufacturer said: „If we can't make the new product feature visible on the market, we will have no way to attract customers”.

4.3 Strategy Developments

This part of the development emphasizes organizational activities. To this end, one must have sufficient mastery over the organization, and each component must be developed in the same way as a new product. The following 6 selection codes will address this main component (Table 4).

4.3.1 Targeting the market

After segmenting the market, the next step is to select one or more market segments as the target. Target selection should take into account criteria such as cost difference, demand level, estimation of demand growth, number of competitors, culture of consumption, etc. (Millson & Wilemon, 2006).

4.3.2 Price contrast with product quality

We can observe two key elements for the manufacturer to optimise the mix of price and product marketing: to try to reduce prices and increase quality (Postma et al., 2012).It's not simple problem! An interviewed producers said: „One of our products is Roham car. Costs increases due to changes in raw material prices put a lot of pressure on our products. We reduce production costs to maintain our price. This kind of product development is still going on in our company”.

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Table 4.
Selection Codes for Strategy Development Categories

Main-Components	Sub-Components	Selective codes
Strategy Development in Modular Platform	Product idea	Targeting the market Price contrast with product quality
	Product Basket	Supplier status and partnership in new product development Continuous improvement
	Specializing in contractors	Development Financial Risk Capability and consideration for future development

4.3.3 Supplier status and partnership in new product development
A manufacturer is only part of the product supply chain (Lam and Chin, 2005). It is advisable for manufacturers to design and develop a new product by using their own platform module to keep current suppliers informed of their future plans. On the other hand, the suppliers also needs to define their future plan according to manufacturers demand. This is a two way interaction.

4.3.4 Continuous improvement
„What comes to your mind as an innovative idea has the potential to be even more fulfilling in the years to come" (Liu et al. 2005). If a company can come up with an innovation, it can benefit from it for years.

4.3.5 Development Financial Risk
The greatest concern for new product design and development using the platform module is the financial risk of investing in the new product (Ozer 2006). Fortunately, scientific advances in economics have made it possible for professionals to determine the reliability of new product design and development.

4.3.6 Capability and consideration for future development
The desire to introduce new technologies in the design and development of new products should be supported by technical capabilities, scientific, technological, financial and human resources. A multi-criteria analysis is needed to identify optimal solutions.

4.4 Organizational Development
Key proponents and energy providers of the new product design and development process should have access to sufficient and effective resources (To et al., 2009). Table 5 summarizes three selection codes extracted from expert opinions.

4.4.1 Continuing Training
The speed of the science and technology development process has forced executives to continually utilize up-to-date human resources and expertise to create a new product design and development using a continuous and sustainable platform module (Lai et al., 2012). The best way to educate and keep experts up to date requires that the training should be continuous and targeted.

Table 5.
Selected codes for resource development categories

Main-Components	Sub-Components	Selective codes
Organizational Development in Modular Platform	Organization with product design and development process capability	Continuing Training Cultivate creativity and create a culture of creativity Absorb with sufficient funds to design and develop a new product

4.4.2 Cultivate creativity and create a culture of creativity
Is not always the way to success to go only with the R&D unit to design and develop a new product using a modules platform. Successful organizations strive to foster the spirit and culture of creativity and ideation at all organizational and occupational levels (Postma et al., 2012).

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4.4.3 Attracting or allocating sufficient funding for new product design and development

Two common ways to finance product development are:

(1) companies allocate a percentage of the profits from the company's entire activity to product development; or, for each product under the future development plan, a percentage of the profits of the same product be saved for development;

(2) the use of banking facilities.

Obviously, outsourcing through stock sale or investor attraction is not recommended at all.

5. CONCLUSION

Regarding the issues raised in this paper, it can be concluded that the first achievement of this research is the introduction of four main categories of success of new product design and development using platform module in Iranian automotive industry including: (1) Technology development, (2) Product structure development, (3) Strategy development, and (4) Organizational development. Production structure development is the basic step in the process of new product design and development using a platform module. This can drive technology development and both will lead to strategy development.

In the meantime, organizational development as the core of the new product design and development process will affect all three other components.

Therefore, in order to develop a new product, the structure of the product must first be addressed. To this end, the uniqueness of the new product, the competitive advantage, the correct positioning of the product, and the capability for future development must be taken into account.

These can also help build effective prototypes in the context of technology development and make it easier to choose new design and production methods. What boosts the confidence in this approach are strategic development plans that include: market segmentation and identifying new potential markets, adjusting marketing mix to suit market conditions, and momentary market dynamics to reduce financial risk and look to the future. The design and development a new product using the platform module not be successful only by relying on one or two sub-components. The complexity of the identified components suggests that the development process is part of the companies' medium and long-term plans.

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Frequency: Quarterly | Electronic publication on: www.ingineria-automobilului.ro
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ISSN 2457 – 5275
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Total of series:	*4*
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Publication frequency:	*Quarterly*
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